

Intra Beam Scattering in RHIC

I. Introduction

II. IBS beam growth and beam loss

emittance, intensity, luminosity

III. IBS Scaling laws

emittance growth, below & above transition

beam loss, Fokker-Planck equation

IV. Future

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Talk at

"Workshop on Machine Backgrounds at RHIC"

I. Introduction

IBS : Intra-beam multiple Coulomb scattering

⇒ main cause of beam growth & loss in RH

* most severe for high charge state ions

scattering cross section $\sim Z^4/A^2$

* severe for high intensity beam

$\sim N$ (number of particle per bunch)

* severe for low emittance beam

$\sim \epsilon_x^{-1} \epsilon_y^{-1} S^{-1}$

* typically slow process

growth time \gg synch. osc. period

* Theoretically approached by many people

A. Piwinsky (1974)

J. Bjorken and S. Mtingwa (1983)

⋮

* Comparison with experimental study

within a factor of 2 on growth rate

(theoretical over-estimate, typical)

II. IBS beam growth and beam loss

$\boxed{\text{Au}^{79+}}$ 10^9 per bunch, ~ 57 bunches

* transverse emittance growth

$$\epsilon_N: 10 \pi \text{ mm}\cdot\text{mr} \rightarrow 40 \pi \text{ mm}\cdot\text{mr}$$

* longitudinal growth, beam loss

fill rf bucket in < 1 hour

then significant beam loss ($\sim 40\%$ in 10^4)

* luminosity reduction

$$\beta^* = 2 \text{ m} : 1.1 \times 10^{27} \rightarrow 1 \times 10^{26} \quad (\text{cm}^{-2} \text{ s}^{-1})$$

$$\beta^* = 1 \text{ m} : 2.2 \times 10^{27} \rightarrow 2 \times 10^{26} \quad (\text{cm}^{-2} \text{ s}^{-1})$$

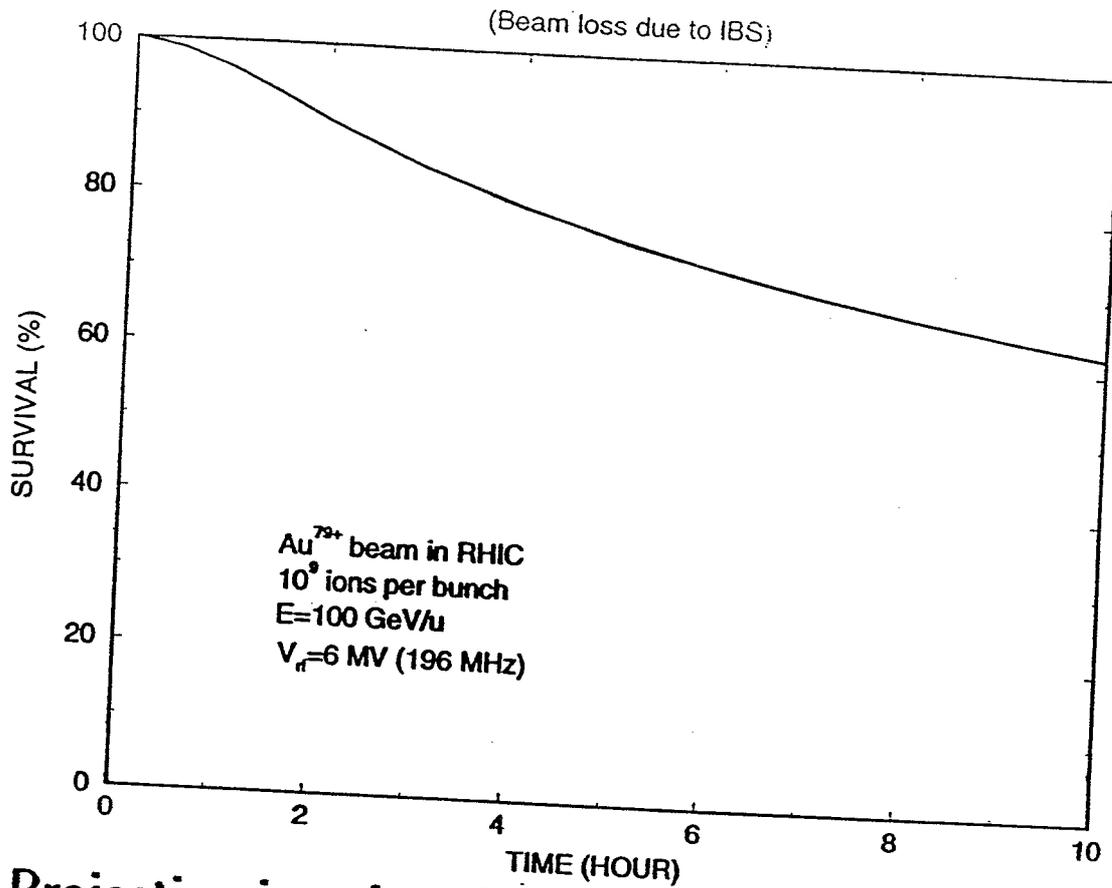
\boxed{p} 10^{11} per bunch, ~ 57 bunches

* transverse : $20 \pi \text{ mm}\cdot\text{mr} \rightarrow 30 \pi \text{ mm}\cdot\text{mr}$

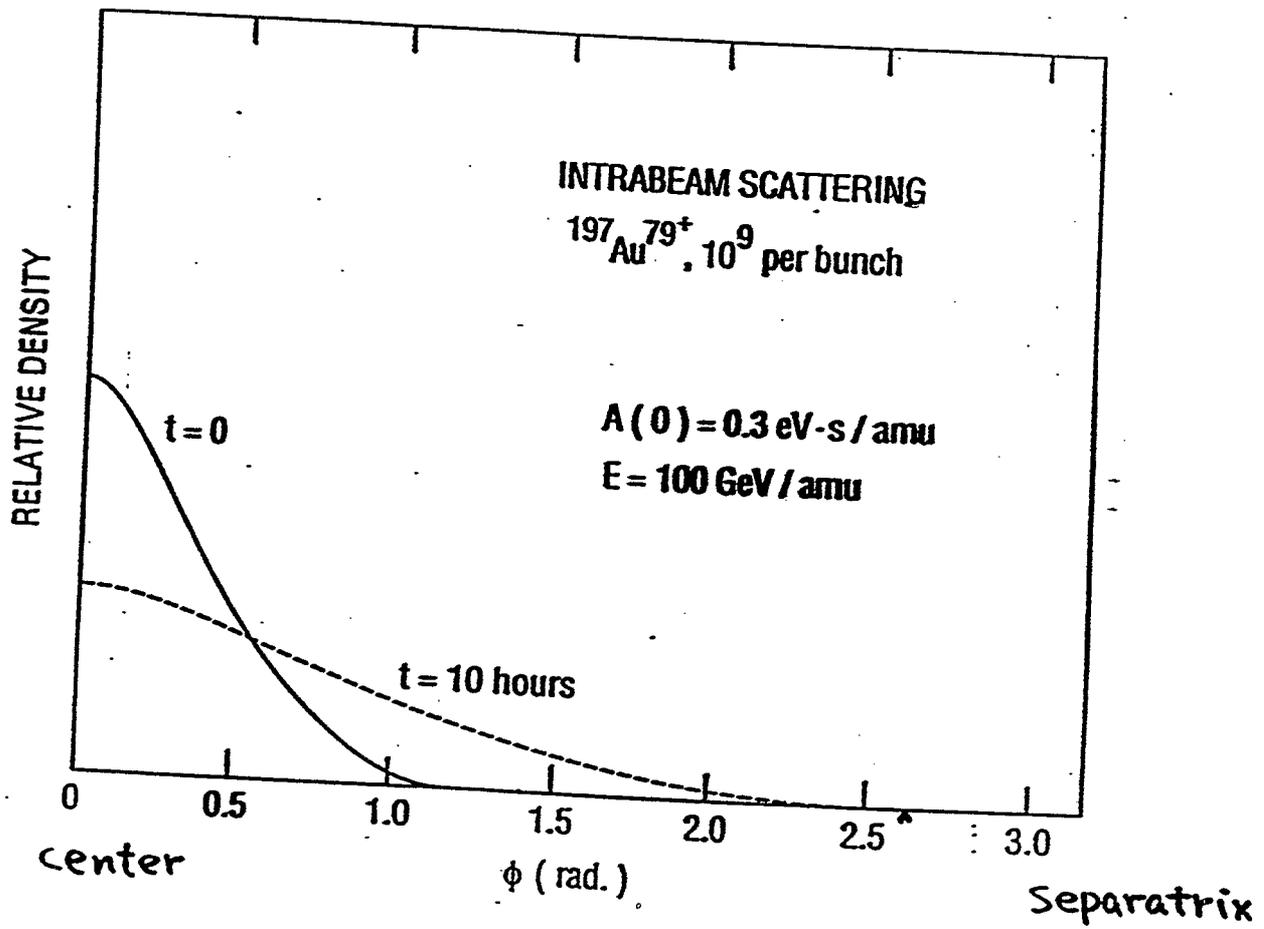
* longitudinal : $0.3 \text{ eV}\cdot\text{s} \rightarrow 1 \text{ eV}\cdot\text{s}$

(rf bucket area $3.1 \text{ eV}\cdot\text{s}$)

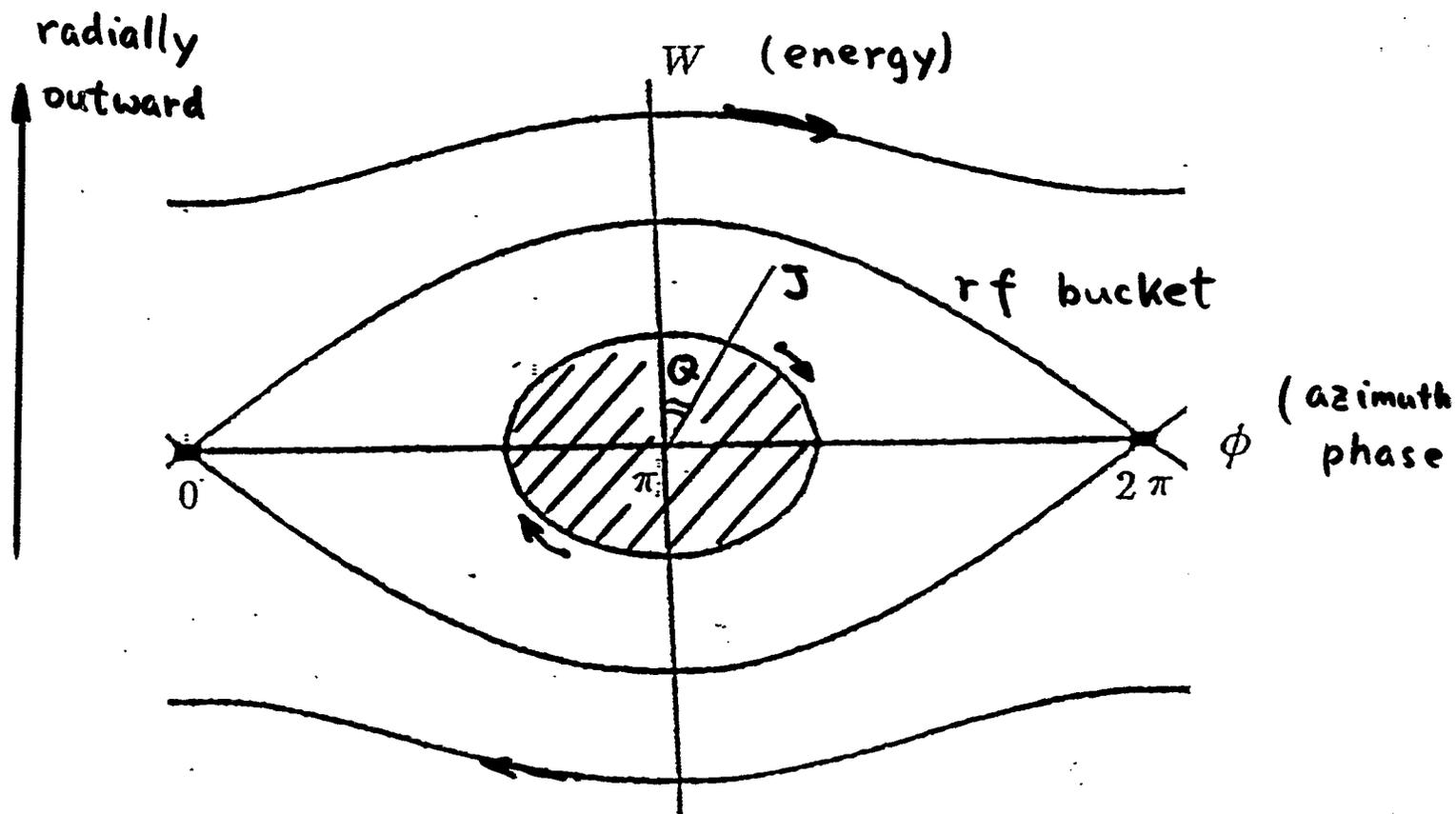
* no beam loss



Projection in azimuthal direction (ϕ):



IBS beam loss



* longitudinal: (mainly)

IBS diffusion

⇒ particles escape out of the bucket

⇒ becomes dc background, beam halo,

or trapped in empty buckets

transverse: ($\beta^* < 1\text{m}$ operation)

particles of large emittance (action) $\epsilon_N \gtrsim 40\pi$

hit physical aperture

Momentum aperture:

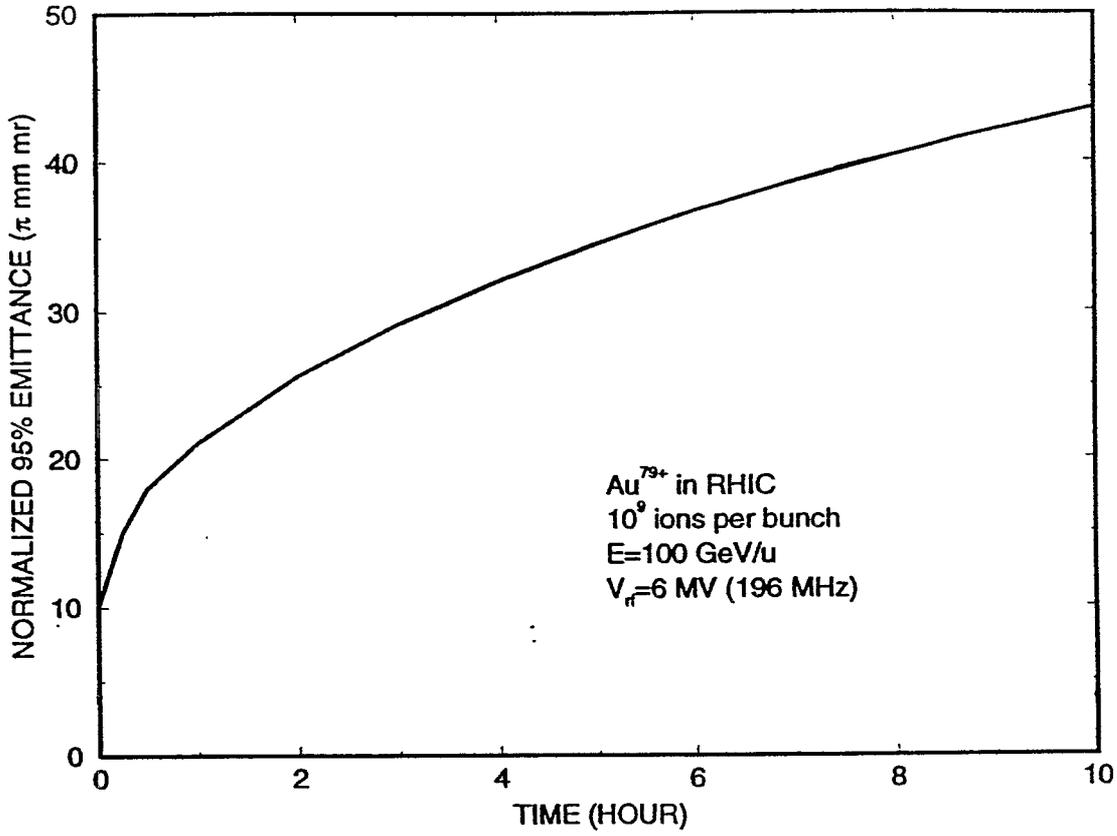
depends on β^* in operation

$$\beta^* = 1 \text{ m,}$$

$\frac{\Delta p}{p}$	Dynamic Aperture	
0	5.5 σ	O.K.
0.002 (95%)	4.5 σ	marginal

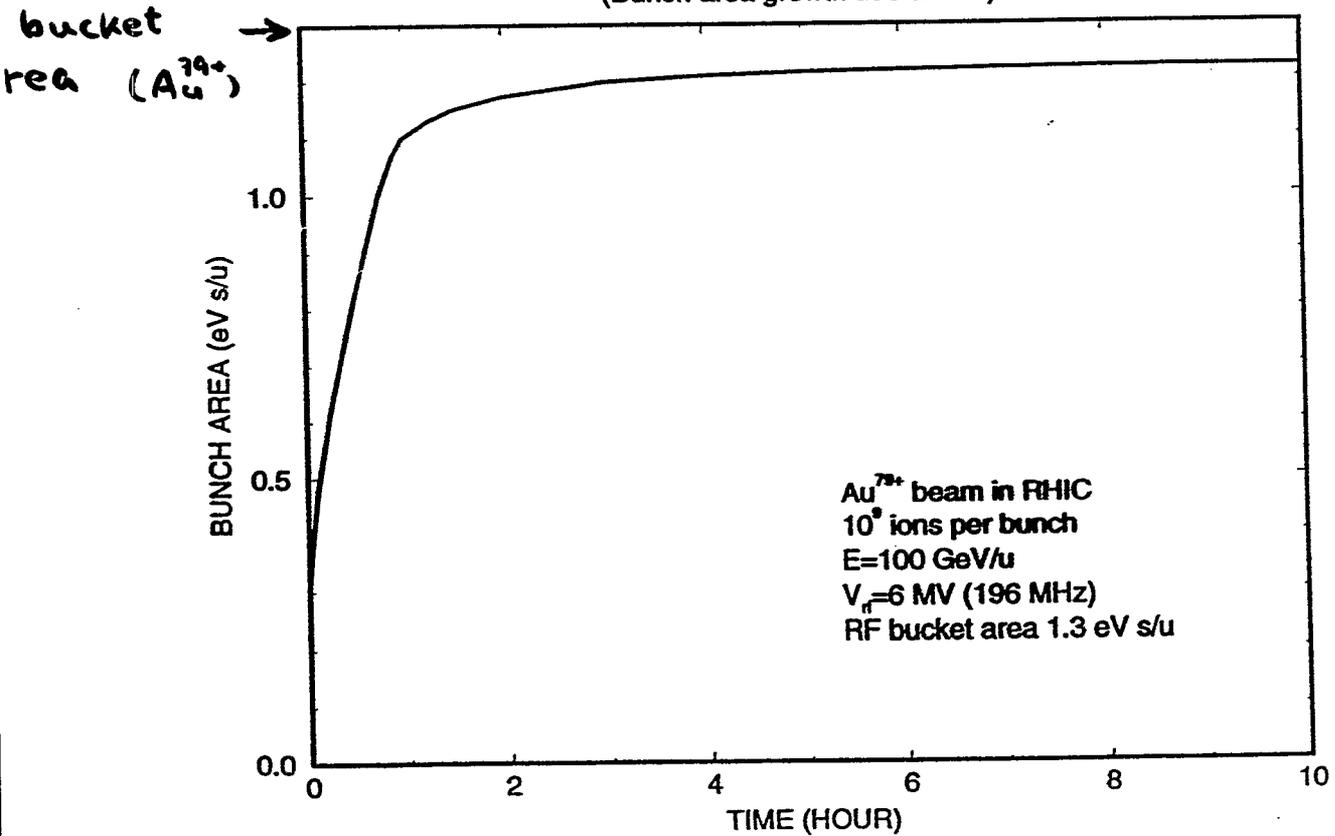
EMITTANCE

(Emittance growth due to IBS)



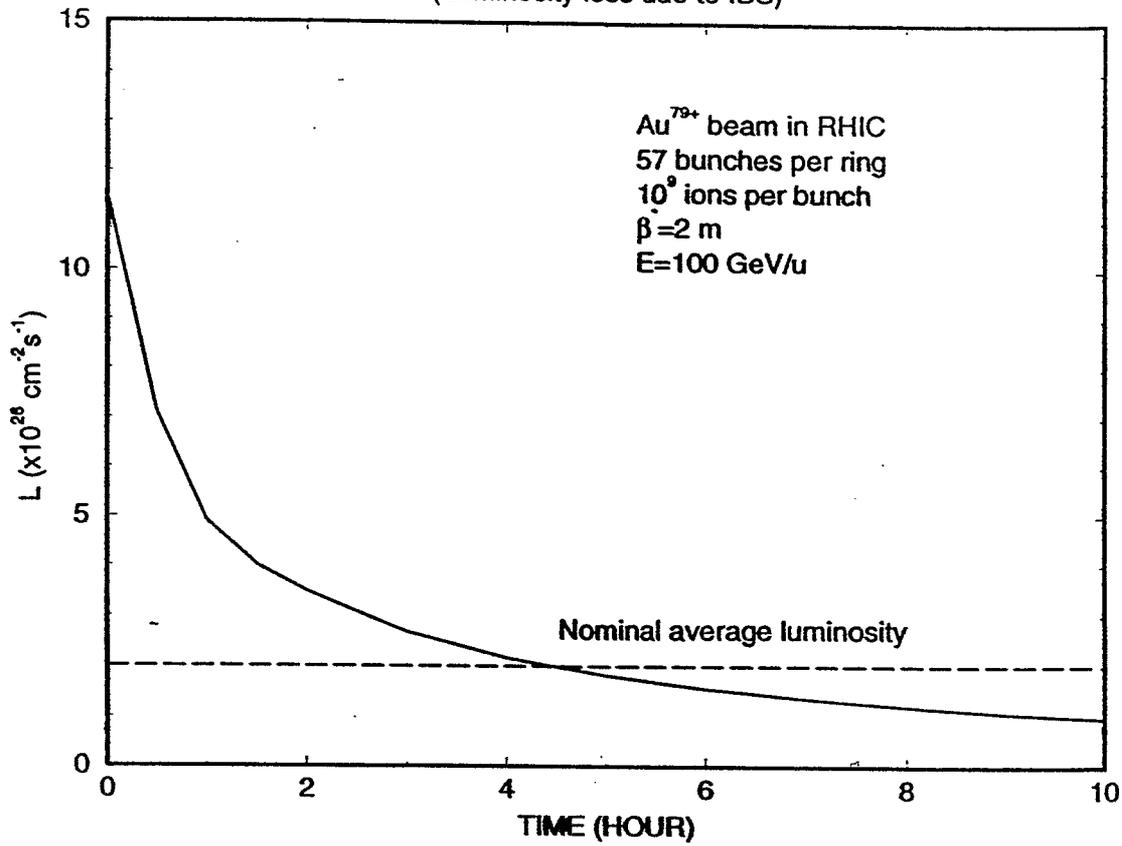
BUNCH AREA

(Bunch area growth due to IBS)



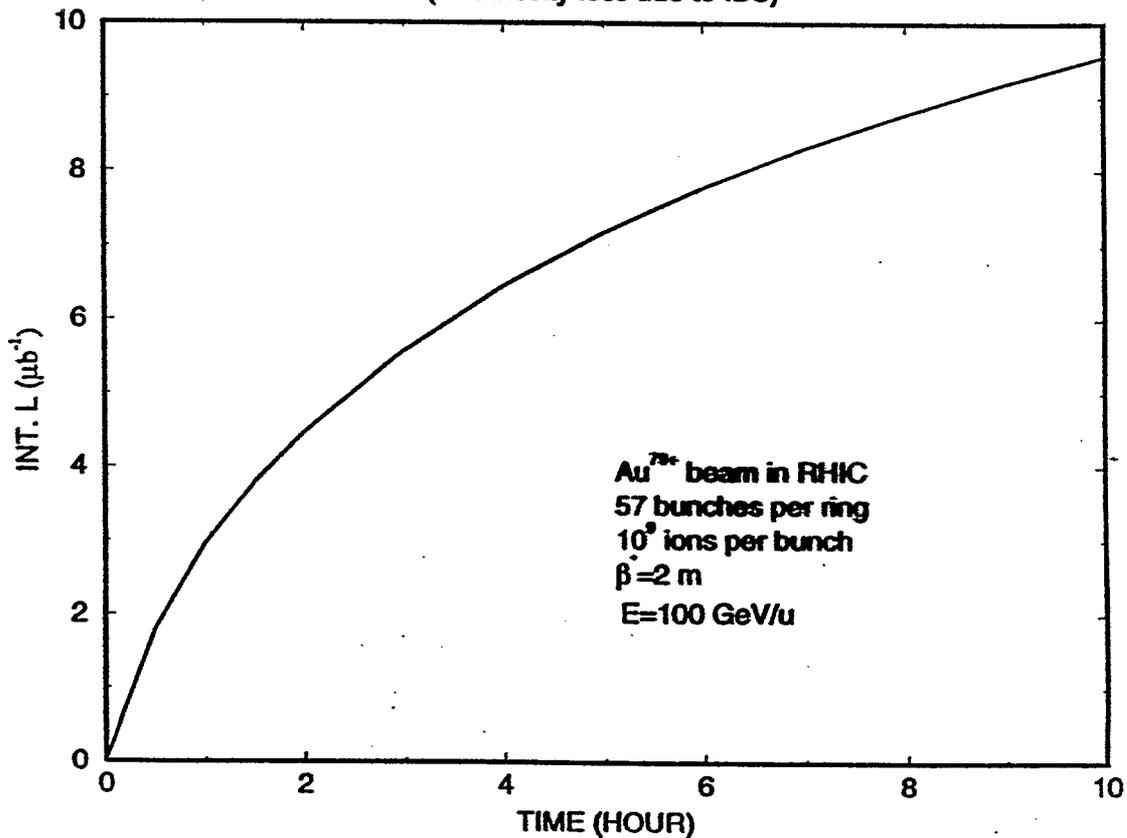
INSTANTANEOUS LUMINOSITY

(Luminosity loss due to IBS)



INTEGRATED LUMINOSITY

(Luminosity loss due to IBS)



Luminosity for a round beam

$$\mathcal{L} = \frac{3}{2\pi} f_{\text{rev}} \cdot N_B \cdot N^2 \cdot \frac{\beta\gamma}{\epsilon_N \cdot \beta^*}$$

N_B : number of bunches

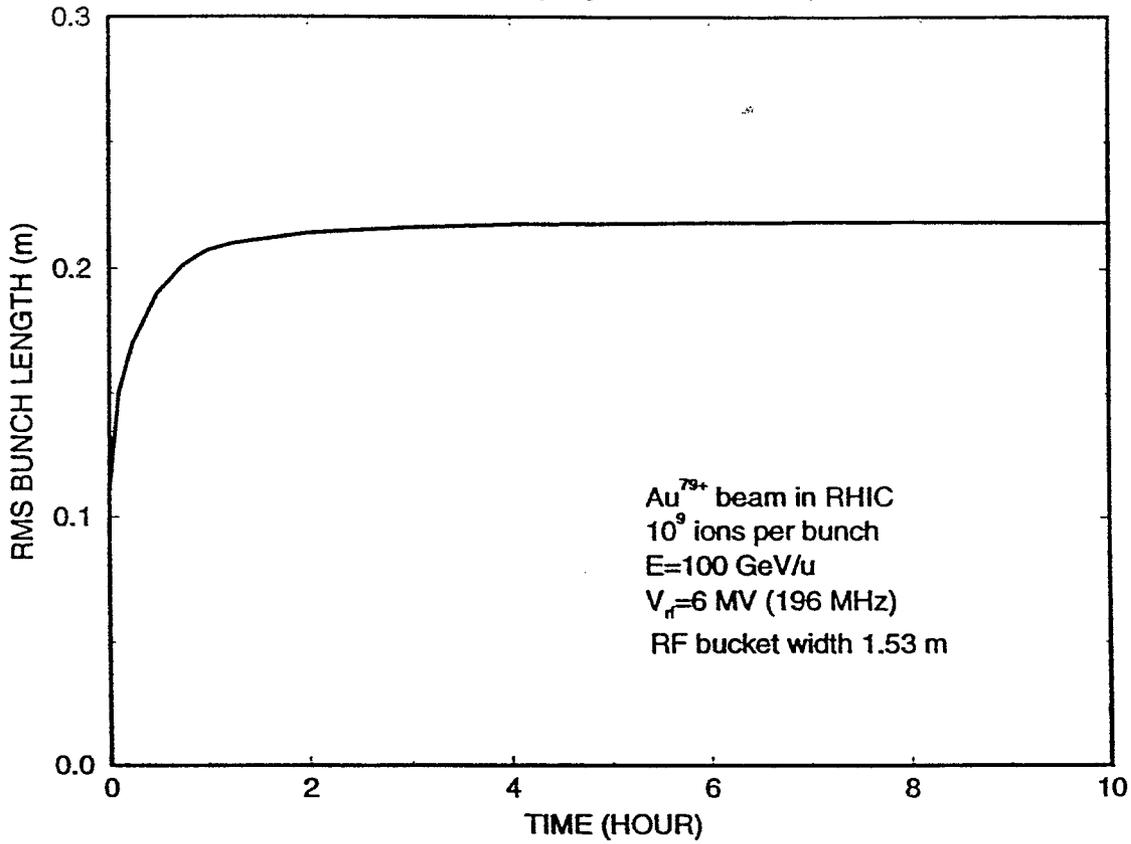
N : number of ions per bunch

$$\epsilon_N = \frac{6 \cdot \beta\gamma \sigma_x \sigma_y}{\beta^*}$$

f_{rev} : revolution frequency

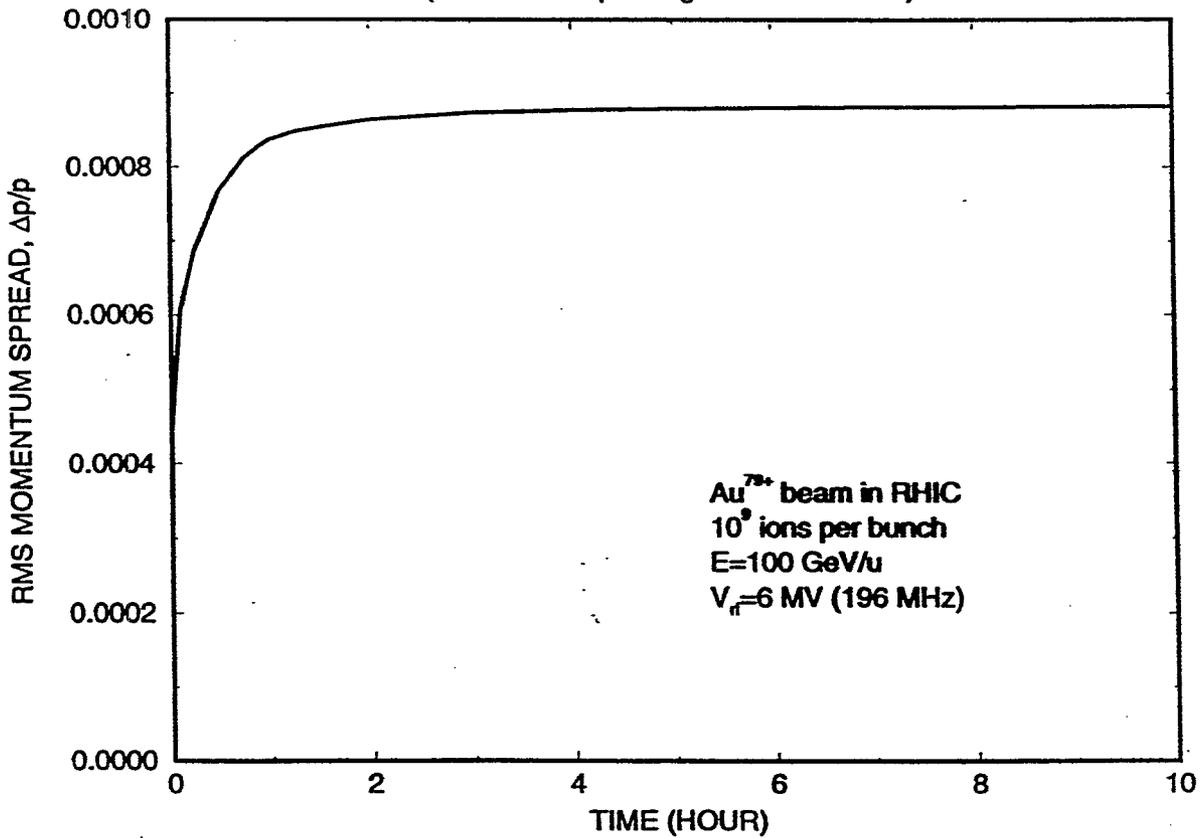
BUNCH LENGTH

(Bunch length growth due to IBS)



MOMENTUM SPREAD

(Momentum spread growth due to IBS)



III. IBS scaling laws

* below transition energy :

similar to gas scattering

⇒ asymptotically approaches isotropic state

$$\langle \frac{\sigma_x}{\beta_x} \rangle \sim \langle \frac{\sigma_y}{\beta_y} \rangle \sim \frac{\sigma_p}{\gamma}$$

growth due to machine lattice variation

heat absorption in a time-dependent system

* above transition energy :

no equilibrium due to negative mass

⇒ asymptotically dispersion related horizontal

and longitudinal dimension

$$n_c \cdot \langle \sigma_x^2 \rangle \sim \langle x_p \rangle^2 \sigma_p^2$$

$$n_c = \begin{cases} 1 & \text{uncoupled} \\ 2 & \text{coupled} \end{cases}$$

continuous growth in both horizontal and longitudinal dimension

Beam growth at high energy $\gamma \gg \gamma_T$

$$\begin{bmatrix} \frac{1}{\sigma_p} \frac{d\sigma_p}{dt} \\ \frac{1}{\sigma_x} \frac{d\sigma_x}{dt} \end{bmatrix} = \frac{Z^4 N}{A^2} \frac{C_0}{\gamma_T \epsilon_x \epsilon_y S} \cdot \begin{bmatrix} (1-d^2)/d \\ d/n_c \end{bmatrix}$$

$$C_0 \equiv \frac{\pi r_0^2 m_0 c^2 L_c}{16}$$

$$d = \langle x_p \rangle \sigma_p / (\sigma_x^2 + \langle x_p^2 \rangle \sigma_p^2)^{1/2}; \quad 0 < d < 1$$

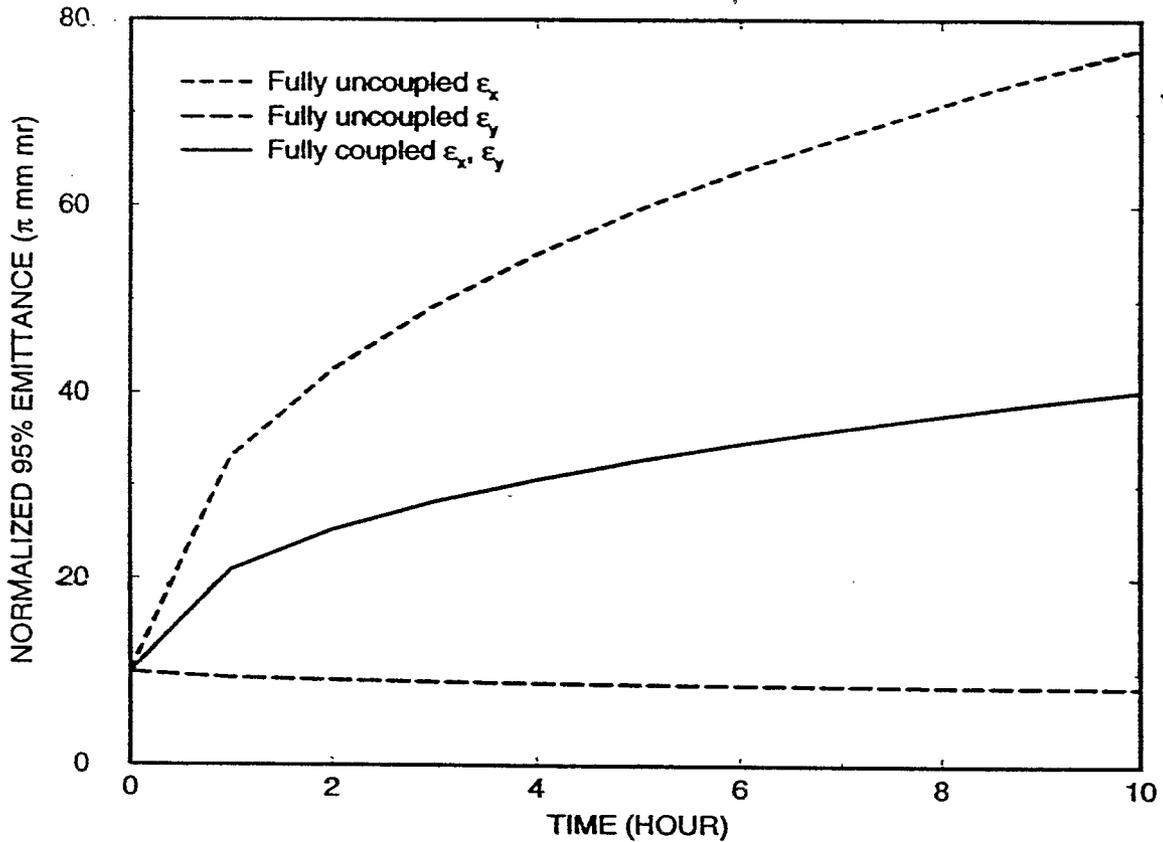
* not sensitive to energy

$$* \tau^{-1} \sim \frac{Z^4}{A^2} \frac{N}{\epsilon_x \epsilon_y S}$$

* transverse growth sensitive to coupling

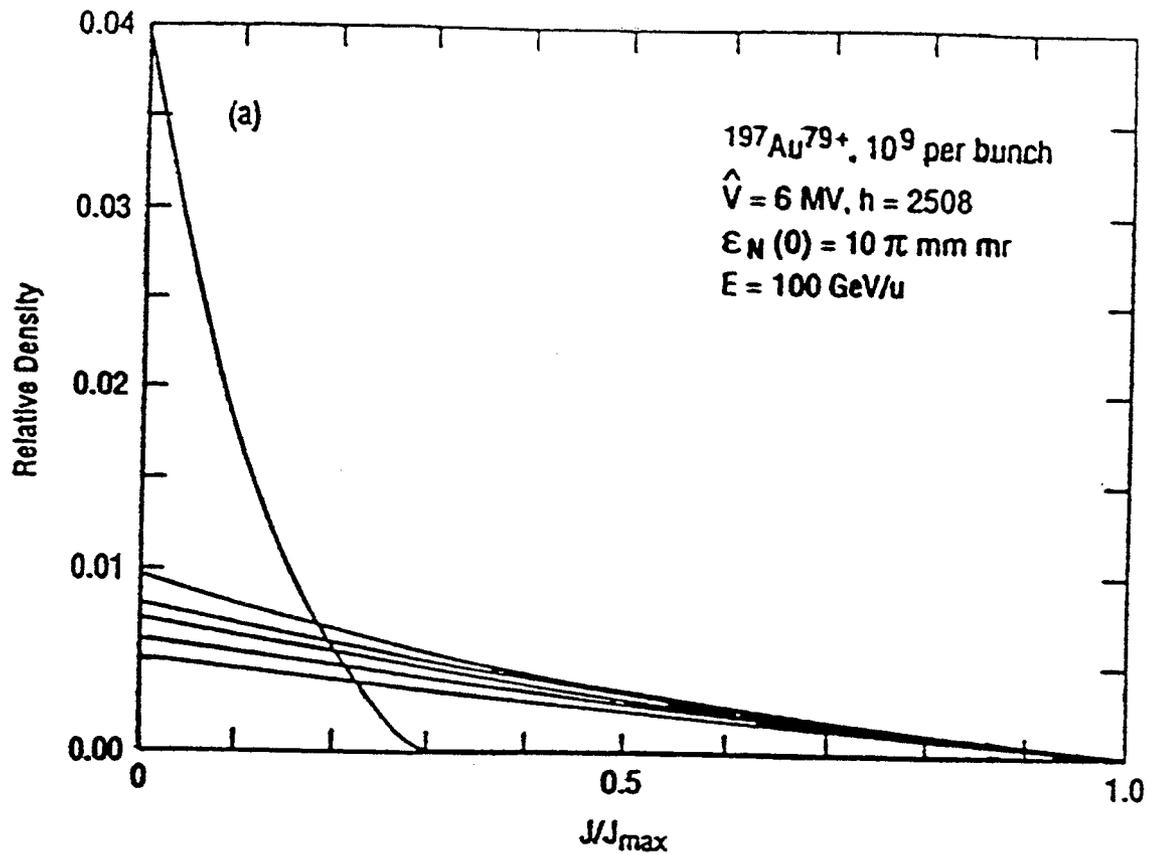
EFFECTS OF COUPLING ON IBS

Au⁷⁹⁺ beam in RHIC. E=100 GeV/u



for $\beta^* = 1$ m operation :

dynamic aperture limit $\Rightarrow \epsilon_{x,y} \sim 40 \pi$ mm·m



Use Fokker - Planck equation to evaluate beam evolution and beam loss

$$\frac{\partial \psi}{\partial t} = - \frac{\partial}{\partial J} (F(J) \psi) + \frac{1}{2} \frac{\partial^2}{\partial J^2} (D(J) \frac{\partial \psi}{\partial J})$$

J : action

ψ : density distribution function

IV. Future

- * Increase the number of bunches per ring
- * An upgrade in rf system (to 16 MV) can reduce beam loss to 2%.

The gain in luminosity is $\sim 30\%$.

may have aperture problem with $\beta^* = 1\text{m}$ operation and $\epsilon_N \sim 48 \pi \text{ mm}\cdot\text{mrad}$

- * Methods like stochastic cooling are desirable to preserve beam quality, alleviate dynamic aperture requirement, and increase luminosity.

